

GEARTECH	QUALITY PROCEDURE	No. QP4100	SHEET 1 OF 5	
		Rev. A		
Gear Design Audit		BY RLE	DATE	9/21/99
		CKD JRM	DATE	9/21/99
1.	Scope			
1.1	This procedure covers rating analysis methods for determining Hertzian and bending fatigue lives, and probability of scuffing per AGMA/AWEA 921-A97 and AGMA 2001-C95. It also includes guidelines for avoiding micropitting.			
2.	Referenced Documents			
2.1	AGMA/AWEA 921-A97 Recommended Practices for Design and Specification of Gearboxes for Wind Turbine Generator Systems.			
2.2	ANSI/AGMA 2000-A88 Gear Classification and Inspection Handbook.			
2.3	ANSI/AGMA 2001-C95 Fundamental Rating Factors and Calculation Methods for Involute Spur and Helical Gear Teeth.			
2.4	GEARTECH Specifications:			
	CK1000	QP1000	Procurement process	
	CK2000	QP2000	Procurement specification	
	CK3000	QP3000	Bid solicitation and evaluation	
	CK4000	QP4000	Gearbox design audit	
	CK4100	QP4100	Gear design audit	
	CK5000	QP5000	Quality assessment	
	CK6000	QP6000	Quality assurance plan	
	CK7000	QP7000	Manufacturing schedule	
	CK8000	QP8000	Manufacturing audit	
	CK8100	QP8100	Gear raw material	
	CK8200	QP8200	Gear tooth cutting	
	CK8300	QP8300	Heat treatment of carburized gears	
	CK8400	QP8400	Gear tooth grinding	
	CK8500	QP8500	Gear tooth inspection	
3.	Terminology			
3.1	Definitions- See referenced documents for definition of terms.			
3.2	Load distribution factor- The ratio of maximum load intensity to mean load intensity. See ANSI/AGMA 2001-C95 for factors influencing load distribution.			
3.3	Dynamic factor- The ratio of dynamic gear tooth load to static gear tooth load. See ANSI/AGMA 2001-C95 for factors influencing dynamic load.			
3.4	Contact temperature- The sum of the gear tooth and flash temperatures. The maximum value along the line of action is compared to the scuffing temperature to assess risk of scuffing.			
3.5	Gear tooth temperature- The equilibrium temperature of the surface of gear teeth before they enter the contact zone. Tooth temperature may be significantly higher than the temperature of oil supplied to the gear mesh.			

GEARTECH	QUALITY PROCEDURE	No. QP4100	SHEET 2 OF 5	
		Rev. A		
Gear Design Audit		BY RLE	DATE	9/21/99
		CKD JRM	DATE	9/21/99
3.6	Flash temperature- The instantaneous rise in gear tooth surface temperature at a given point along the line of action resulting from combined effects of gear tooth geometry, load, friction, velocity and material properties.			
3.7	Scuffing temperature- The contact temperature at which scuffing is likely to occur with the chosen combination of lubricant and gear materials. The mean scuffing temperature is the temperature at which there is a 50% chance scuffing will occur.			
3.8	Lubricant dynamic viscosity- The viscosity used in lubricant film thickness calculations is dynamic viscosity measured in units of centipoise (cP). ANSI/AGMA 2001-C95 Annex A gives values of dynamic viscosity versus gear tooth temperature.			
3.9	Lubricant pressure-viscosity coefficient- Calculations of lubricant film thickness require the pressure-viscosity coefficient, which characterizes exponential increase in viscosity with pressure. ANSI/AGMA 2001-C95 Annex A gives values of pressure- viscosity coefficient versus gear tooth temperature.			
3.10	Lubricant micropitting resistance- A standard test used to determine micropitting resistance in accordance with FVA-Information Sheet "Micropitting," No. 54/7 (July 1993) Forschungsvereinigung Antriebstechnik e.V., Lyoner Strasse 18, D-60528 Frankfurt/Main.			
3.11	Aspect ratio- The ratio of pinion face to pinion operating pitch diameter.			
3.12	Transverse contact ratio- The ratio of the angle of action to angular pitch. It is a measure of the number of teeth in contact and smoothness of gear tooth meshing.			
3.13	Axial contact ratio- The ratio of active face width to axial pitch. It is a measure of the number of teeth in contact and smoothness of gear tooth meshing.			
3.14	S_{at} – The allowable bending stress number per ANSI/AGMA 2001-C95.			
4.	Significance and Use			
4.1	Gear rating analysis- The gear design audit determines if gears have adequate load capacity to conform to requirements of AGMA/AWEA 921-A97 and the procurement specification. AGMA standards do not provide rating methods for micropitting lives, but this quality procedure suggests methods for minimizing probability of micropitting.			
5.	Procedure			
5.1	Checklist and quality procedures- CK1000 through CK4000 and QP1000 through QP4000 shall be used as guidelines for required data for gear design audits. CK4100 shall be used as a guideline for gear design audits.			
5.2	Specification conformance- Gear rating calculations shall be performed in accordance with AGMA/AWEA 921-A97 and the procurement specification.			
5.3	Metallurgical quality- AGMA/AWEA 921-A97 requires metallurgical quality meeting requirements for grade 2 material in accordance with ANSI/AGMA 2001-C95, with exceptions on core hardness, cleanliness, surface temper, and hardenability. If the gear manufacturing audit shows all gears meet requirements of grade 2 material, design audit calculations may assume grade 2 metallurgical quality. See CK5000 through CK8500, and QP5000 through QP8500.			

GEARTECH	QUALITY PROCEDURE	No. QP4100	SHEET 3 OF 5
		Rev. A	
Gear Design Audit		BY RLE	DATE 9/21/99
		CKD JRM	DATE 9/21/99

- 5.4 Geometric quality- AGMA/AWEA 921-A97 requires geometric quality meeting requirements for Q11 accuracy in accordance with ANSI/AGMA 2000-A88. If the gear manufacturing audit shows all gears meet requirements of Q11, design audit calculations may assume Q11. See CK8500 and QP8500.
- 5.5 Load distribution factor- The load distribution factor may be calculated using the empirical method of ANSI/AGMA 2001-C95. However, a value ≥ 1.25 shall be used.
- 5.6 Dynamic factor- The dynamic factor may be calculated using the empirical method of ANSI/AGMA 2001-C95. Transmission accuracy number (Q_v) shall be based upon the quality of the gears. However, Q_v shall not exceed $Q_v = 11$ for rating purposes.
- 5.7 Hertzian fatigue
- 5.7.1 Macropitting life rating- Calculations shall be performed per Section 4.3.1 of AGMA/AWEA 921-A97, Gear life rating and CK4100.
- 5.7.2 Micropitting resistance- Wind turbine gears require smooth surfaces to ensure adequate load capacity. This is especially important for micropitting resistance. Maximum surface roughness shall be as specified in Table 1.

Table 1 Maximum Gear Tooth Surface Roughness	
Gear	Maximum Roughness R_a (μm)
HS pinion and gear	0.7
INT pinion and gear	0.7
LS pinion and gear	0.6
LS sun and planet	0.5

Lubricant viscosity shall conform to requirements of AGMA/AWEA 921-A97.

Lubricant micropitting resistance shall be ≥ 10 failure load stage in accordance with FVA project number 54 test.

Active flanks of gear teeth shall not be shot peened because shot peened flanks may produce micropitting on mating gear teeth.

For maximum micropitting resistance, pinions should be at least 2 HRC points harder than gears. This is especially important for sun pinions.

See AGMA/AWEA 921-A97, Annex G for further information about surface roughness and boundary lubrication.

- 5.8 Bending fatigue
- 5.8.1 Bending fatigue life rating- Calculations shall be performed per Section 4.3.1 of AGMA/AWEA 921-A97, Gear life rating and CK4100.

GEARTECH	QUALITY PROCEDURE	No. QP4100	SHEET 4 OF 5	
		Rev. A		
Gear Design Audit		BY RLE	DATE	9/21/99
		CKD JRM	DATE	9/21/99
5.8.2	Idler and planet gears- Calculations shall use 70% of S_{at} for idler and planet gears.			
5.9	Scuffing probability			
5.9.1	Scuffing probability- Calculations shall be performed per Section 4.3.1 of AGMA/AWEA 921-A97, Gear life rating and CK4100.			
5.9.2	Scuffing temperature- If scuffing temperature is determined from FZG tests, one load stage lower than the failure load stage shall be used for scuffing analysis.			
5.9.3	Load for scuffing analysis- Contact temperature shall be calculated using the maximum load in the load spectrum.			
5.9.4	Surface roughness for scuffing analysis- Contact temperature shall be calculated using the as-manufactured surface roughness of gear teeth.			
5.10	Wear probability			
5.10.1	Wear probability- Calculations shall be performed per Annex A of ANSI/AGMA 2001-C95.			
5.10.2	Lubricant properties- Dynamic viscosity and pressure-viscosity coefficient shall correspond to the gear tooth temperature. ISO viscosity grade and lubricant cleanliness shall conform to requirements of AGMA/AWEA 921-A97.			
5.10.3	Load for wear analysis- Specific film thickness shall be calculated using the maximum load in the load spectrum.			
5.10.4	Surface roughness for wear analysis- Specific film thickness shall be calculated using the run-in surface roughness of gear teeth.			
6.	Interpretations of results			
6.1	Specification conformance- Results of the gear design audit shall be compared to requirements of AGMA/AWEA 921-A97 and the procurement specification for the following categories: <ul style="list-style-type: none">• Macropitting life• Micropitting resistance• Bending fatigue life• Scuffing probability• Wear probability• Design features			
7.	Acceptance criteria			
7.1	Macropitting life- The macropitting life of all gears shall be $\geq 175,000$ hours.			
7.2	Micropitting resistance- Gears shall conform to the requirements of clause 5.7.2.			
7.3	Bending fatigue life – The bending fatigue life of all gears shall be $\geq 175,000$ hours.			
7.4	Scuffing risk- The scuffing risk for all gears shall be $< 5\%$.			
7.5	Wear risk- The wear risk for all gears shall be $< 5\%$.			

GEARTECH	QUALITY PROCEDURE	No. QP4100	SHEET 5 OF 5	
		Rev. A		
Gear Design Audit		BY RLE	DATE	9/21/99
		CKD JRM	DATE	9/21/99
7.6	Design features- Gear design features shall meet the requirements of AGMA/AWEA 921-A97 and the procurement specification.			
8.	Report			
8.1	Report- The report shall include the following:			
8.1.1	Summary of macropitting life ratings,			
8.1.2	Summary of micropitting resistance,			
8.1.3	Summary of bending fatigue life ratings,			
8.1.4	Summary of scuffing probabilities,			
8.1.5	Summary of wear probabilities,			
8.1.6	Summary of design features,			
8.1.7	Recommendations for revisions to engineering specifications to ensure conformance to AGMA/AWEA 921-A97 and the procurement specification.			